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Energy optimization in IP-over-WDM networks

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ABSTRACT

The energy crisis and environmental protection are gaining increasing concern in recent years. ICT (Information and Communication Technology) has a significant impact on the total electricity consumption all over the world. Telecom networks, being an important part of ICT, consume significant energy since more network equipment is deployed annually. Specifically, in IP-over-WDM networks, energy is consumed by network elements at both IP and WDM layers. Routers in the IP layer are the largest energy consumer in this architecture, and current network infrastructures have no energy-saving scheme, so a large amount of energy is wasted when traffic load is low. In this paper, we propose a novel approach to save energy in IP-over-WDM networks by shutting down idle line cards and chassis of routers based on time-of-the-day network traffic variation. A method based on Mixed Integer Linear Programming (MILP) is proposed to ensure that the energy cost incurred by the IP routers and optical cross-connects is minimized by our approach. We also propose some possible approaches to minimize potential traffic disruption when the network elements are shut down.

1. Introduction

Energy efficiency has been gaining increasing interest in our society in recent years. In particular, energy consumption of ICT (Information and Communication Technology) is increasing fast, since more equipment for networking and communication is being deployed annually. From the data of 2009, ICT consumes about 8% of the total electricity all over the world [1]. Although this percentage is not high, the energy consumption of ICT is still considerable because the total amount of electricity usage in the world is enormous. Telecom networks, which represent a significant part of the ICT, are penetrating further into our daily lives. The traffic volume of broadband telecom networks is increasing rapidly and so is its energy consumption. Considering both the growing energy price (expected with the decline of availability of cheap fossil fuels) and the increasing concern on the greenhouse effect, the energy consumption of ICT is already raising questions. It is imperative to develop energy-efficient telecom solutions. We need to design new networking paradigms so that telecom networks will maintain the same level of functionality while consuming less energy in future.

IP-over-WDM is a promising network architecture for next-generation telecom networks. In an IP-over-WDM network, energy is consumed in both electronics (e.g., IP) and optics (e.g., WDM). IP routers, switches, network gateways, etc. consume most of the energy in electronics (which is loosely referred to as the IP layer here), while optical cross-connects (OXCs), EDFAs, and transmitters are the main energy consumers in optics (which is loosely referred to as the physical layer). According to recent research of energy efficiency, electronic devices in the IP layer, especially routers, consume much more energy than optical devices in the physical layer [2]. Therefore, saving

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energy at the IP layer should be very beneficial to this two-layer network infrastructure.

Traffic load in an IP-over-WDM network is always varying as a consequence of users' behavior over various times of the day. However, in current telecom networks, energy consumption of network equipment is not considered as a critical issue so that majority of the IP routers of the network are kept powered-on day and night without concerning their levels of utilization. In this case, a large amount of energy is wasted when the traffic load is low. To improve this situation, in this paper, we propose a novel scheme to reduce the energy consumption of IP-over-WDM networks, especially in the IP layer, according to the traffic variation during the time of the day. When the traffic load is low (at night or in early morning), line cards and chassis of IP routers can be of very low utilization or idle. In this case, we shut the idle line cards and chassis down and reroute the affected traffic, thereby saving the energy consumed by them. If all the line cards of a chassis are shut down in our scheme, we also shut down this chassis to save the energy consumed by this idle chassis. On the contrary, if traffic load increases and additional line cards and chassis are needed, we turn them on. When this equipment is being shut down or turned on, traffic interruption may occur since re-routings are needed. In this case, our approach is also focusing on minimizing the amount of reconfiguration of network elements and reroutings, so that potential traffic interruptions can be minimized.

This paper is organized as follows: Section 2 introduces related work published in recent years; Section 3 formally states the problem; Section 4 proposes a method based on Mixed Integer Linear Programming (MILP) to minimize the network-wide energy cost and potential traffic disruptions; Section 5 provides numerical results; and Section 6 concludes the paper.

2. Related work

Recently, more and more literature has been published on energy efficiency in telecom networks. In general, the related works can be divided into three categories: energy-efficient network design, green traffic grooming, and selectively turning down network elements.

On "energy-efficient network design", the authors in [3] propose an approach of network design and planning which minimizes energy consumption of IP-over-WDM networks by studying energy usage of components in both IP and physical layers and using total energy consumption as the objective of network design.

On "green traffic grooming", in [4], total energy consumption of an optical WDM network is modeled in terms of the energy consumed by individual lightpaths. An ILP (Integer Linear Program) formulation of the energy-aware grooming problem is defined. In [5], the authors propose both an MILP and a heuristic approach to solve the routing and wavelength assignment and decrease the number of lightpath interfaces in order to minimize the energy consumption of the network. In [6], the authors consider the energy consumed by each network operation needed while grooming traffic in optical backbone networks. Energy consumption of every operation in traffic grooming is investigated, and an auxiliary-graph based model is proposed to identify the energy consumed by the operations. Results show that energy-aware traffic grooming saves a significant amount of energy compared to the traditional traffic grooming scheme. In [7], the authors focus on the energy-aware dynamic traffic grooming problem in optical networks, with the methodology of auxiliary graph.

As for "selectively turning down network elements", the authors in [8] propose a scheme to reduce energy consumption by switching off idle physical nodes and links in a hierarchical network topology according to the traffic variation during time of the day. But shutting down physical nodes or links may lead to much longer routes for some traffic demands, so the performance of the whole network may be affected. The authors in [9] also propose an approach to selectively switching off optical links. Furthermore, in [10], a scheme is proposed to shut down idle line cards (and corresponding optical circuit, or lightpath, associated with the line cards) when the traffic load is low. Note that shutting down lightpaths may lead to undesirable traffic disruptions but this problem is not addressed. As a further difference with respect to [10], in our approach, when traffic load is low, we shut down not only idle line cards, but also the chassis of IP routers. This will lead to: changes only in the virtual-network connectivity, without affecting the underlying physical topology. Also, we minimize the amount of network reconfigurations, such as reconfiguration of connectivity of line cards and lightpaths, to minimize the potential traffic disruption when the line cards and chassis of IP routers are being shut down. In addition, we also consider minimizing the energy consumption from OXCs in the network.

Today, telecom networks are going through technological changes to support enormous data traffic while controlling their energy consumption. Our research is a timely one which can enable carriers to design energy-efficient networks (and their energy-efficient upgrade) by dynamically reconfiguring network devices, i.e., shutting down idle network elements to save energy, ensuring a minimal impact on the living traffic served by the network.

3. Problem statement

3.1. Motivation of time-aware energy optimization

Traffic load in telecom networks is determined by the behavior of users who are using the network. In general, most enterprise and residential network users access the Internet in the daytime or evening, respectively, which induces high bandwidth utilization of the network concentrated in some specific times of the day. On the contrary, during early morning or after midnight, the traffic demand by users reduces significantly to a much lower level.

Some institutions have done some investigations on user behaviors of the telecom networks. As an example, Fig. 1 shows the real-time traffic load variation of Internet in Netherlands during time of the day. It is measured by service provider AMS-IX in Amsterdam [11]. From 6:00 to 16:00, the traffic load increases continuously. It is because